LAB REPORT

FIBER-OPTIC EXPERIMENT

WEEK-1, 2

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Determination of Bending Loss in an Optical Fiber

Aim: The experiment aims to determine the bending loss in various radii of curvature of the bend.

Equipment and Components:

- Diode Laser (with power supply)
- Bread Board/Graduated Optical Rail
- Bending loss apparatus
- Laser fiber coupler
- Fiber chuck holder
- Detector output measurement unit with a translation stage
- Fiber samples (preferred 2)

Theory:

Attenuation refers to the reduction of something, but in optical fiber, one of the primary factors of attenuation is by the bending effect on the fiber.
Optical fibers work on the basic principle called "Total Internal Reflection". When the light is incident on the surface of the optical fiber, if the angle of incidence is more than the specified "Critical Angle" of the medium, the light rays are reflected into the surface, which is called "Total Internal Reflection". We consider the optical fiber material based on the wavelength range of the transmission.

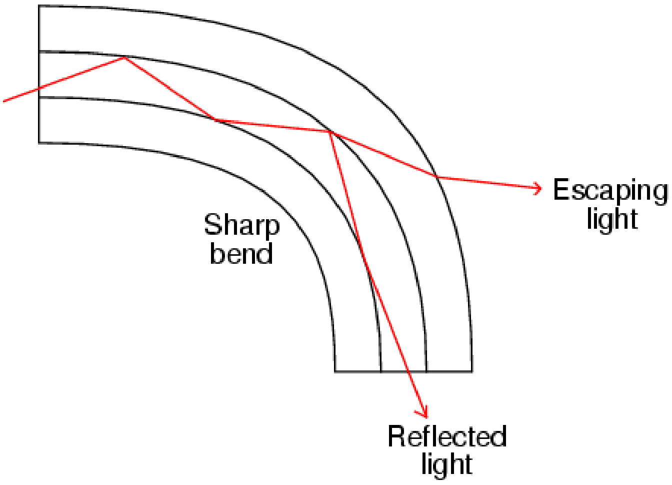


Fig.1

When we bend the optical fiber, the bend causes the light rays to incident at a different angle on the material rather than the initial angle in which it was considered straight. As the curvature of the bend increases, we can see that the transmitting laser ray will be incident at an angle that is comparatively lesser than the incidence in which the curvature is less. In this way, the bend in the fiber causes a loss in emittance and an increase in attenuation (the rate of reduction) as the angle of incidence decreases at the points which have a smaller radius of curvature (sharper curves). As the curve becomes sharper, total internal reflection cannot take place, and as the incidence angle is less than the critical angle of the fiber, this causes Refraction and leads to a loss in energy transmitted to the other end of the optical fiber. This causes power loss.
In the given apparatus, we bend the fiber using the bending apparatus and determine the bending loss and the correlation between the radius of the curvature and the loss in power.

Procedure:

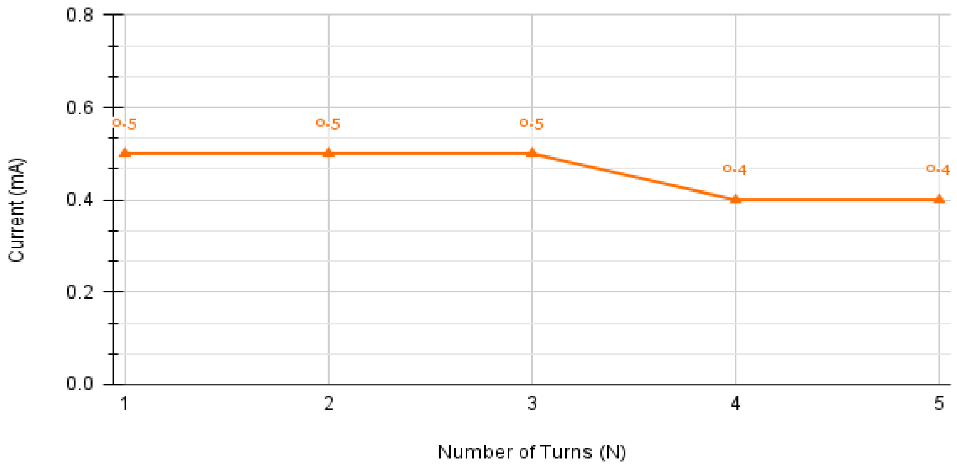
1. Mount the diode laser to the laser mount
2. Mount fiber on the Laser-fiber coupler.
3. Collimate the laser beam to the fiber.
4. Fine adjustments can be made by tilting the fiber positioned.
5. Fix the output end of the fiber to the fiber chuck holder.
6. Place the pin-hole detector nearer to the tip of the fiber output.
7. Find out the maximum intensity region and keep it unaltered.
8. Place the bending loss apparatus in between the laser fiber coupler and fiber chuck holder.
9. Place fiber on various diameters and take the necessary measurements.

Observation:

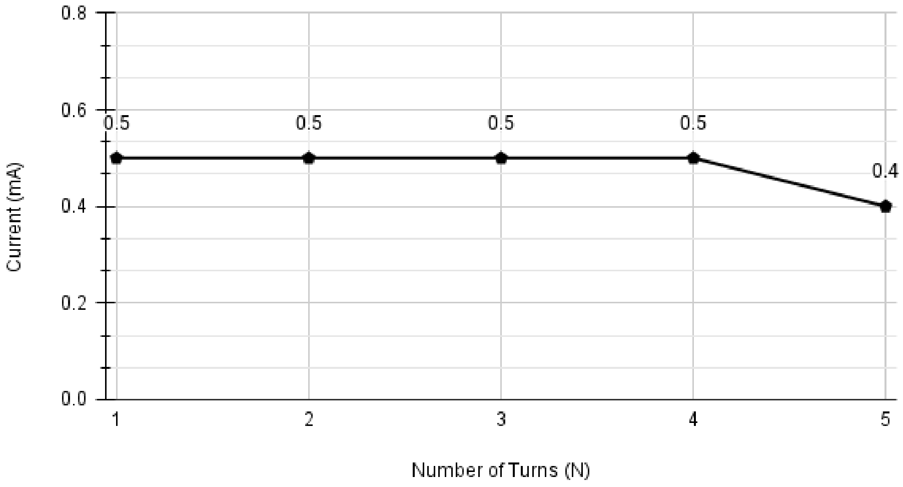
The Readings of the output current based on the diameter of the curved section and the output current on a variable number of turns are as follows. P_0= 0.5 mA

Diameter (d) (cm)	Number of Turns (n)	Current (I) (mA)	P/P_0	$\log_{10}(P/P_0)$	dB = $10 \log_{10}(P/P_0)$
3.5	1	0.5	1	0	0
	2	0.4	0.8	-0.0969	-0.969
	3	0.4	0.8	-0.0969	-0.969
	4	0.4	0.8	-0.0969	-0.969
	5	0.3	0.6	-0.2218	-2.218
4.5	1	0.5	1	0	0
	2	0.5	1	0	0
	3	0.5	1	0	0
	4	0.4	0.8	-0.0969	-0.969
	5	0.4	0.8	-0.0969	-0.969
5.5	1	0.5	1	0	0
	2	0.5	1	0	0
	3	0.5	1	0	0
	4	0.5	1	0	0
	5	0.4	0.8	-0.0969	-0.969
6.5	1	0.5	1	0	0
	2	0.5	1	0	0
	3	0.5	1	0	0
	4	0.5	1	0	0
	5	0.5	1	0	0

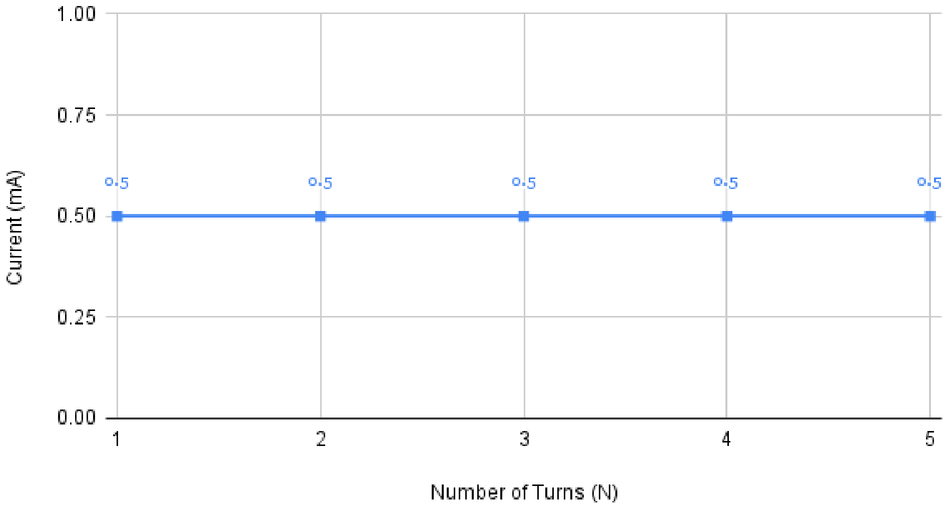
Diameter = 4.5cm



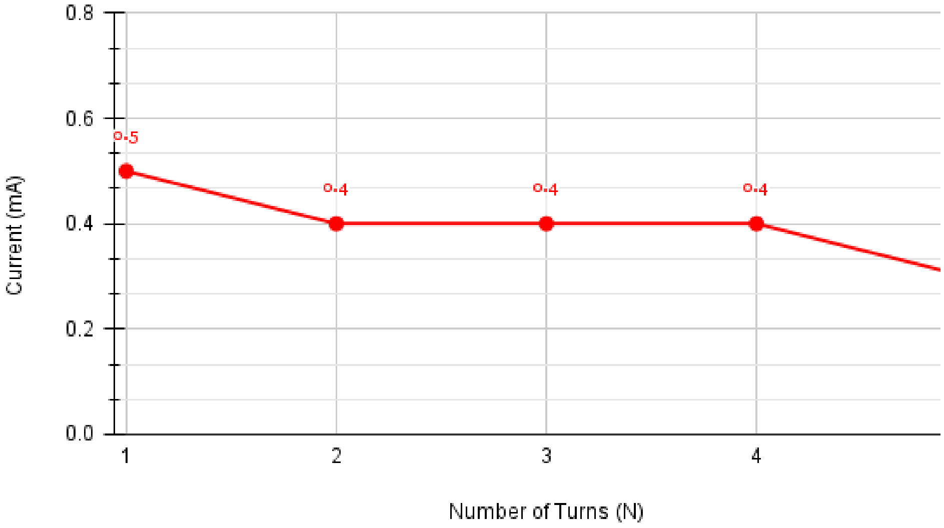
Diameter = 5.5 cm



Diameter = 6.5 cm



Diameter = 3.5 cm



Discussion:

We can observe that as we turn our fiber across the bending apparatus in various radii and the number of turns, the radius of curvature, in this case, the diameter considered can be determined as a major parameter which causes the bending loss significantly. We use the number of turns as a physical or applicative factor because the more the number of turns in a particular diameter, the more accurate the result is. This is why we use the number of turns as another parameter to determine the bending loss. We can clearly observe from the readings that the smaller the diameter, the more bending, and more power loss. So we see a significant attenuation when the fiber was wielded around the diameter of 3.5 cm. As the number of turns increases, the more accurate the diameter of the curve will be signified and the significant change in output current can be observed.

But, as the diameter increases, the radius of curvature increases and the curves are less sharp, and hence the angle of incidence will not change drastically such that it leads to a significant loss due to bending. So the readings of the output current are approximately the same in the higher diameter readings, and this shows us that the diameter can be considered the primary factor in determining the bending loss in Optical Fiber.

Result:

This experiment successfully demonstrated that the bending loss caused in an Optical fiber is primarily dependent on the radius of the curvature of the bend, which can also be called “Bending Radius” and found that the bending loss increases as the diameter of the bend (d) decreases.

Precautions:

- Make sure to not bend the fiber too sharp such that a breakage might occur.
- Make sure that the fiber ends are aligned carefully at the laser fiber coupler and the other end is aligned with the pinhole of the detector.
- Do not see the laser through your eye directly.

Measurement of the Numerical Aperture

Aim: To determine the numerical aperture of a given optical fiber from the measurement on the far field of the fiber and acceptance angle.

Equipments and Components:

- Diode Laser with Power Supply
- Bread Board or Graduated Optical Rail
- Detector Output measurement unit with translation stage
- Laser Fiber Coupler
- Fiber Chuck Holder
- Fiber Samples, etc.

Theory:

The Numerical Aperture (NA) is considered a parameter, as it represents the measure of how much light can be collected by an optical fiber. Formula-wise, it is defined as the product of the refractive index of the incident medium and the sine of the acceptance angle. Numerical Aperture can also be considered as a dimensionless number that characterizes the range of angles over which the optical fiber can accept or emit light. The numerical aperture is used to describe the acceptance cone in which a cone of light is accepted into the fiber or we can consider exiting the fiber. It refers to the maximum aperture angle at which the incident light on the fiber is totally internally reflected and can be transmitted properly along the fiber.

Let us consider an optical fiber with the core refractive index as n_i and the surrounding medium as n_0. Let us consider that the light is incident on the optical fiber such that the incident light rays are refracted in the core. Then we consider the angle of the light ray which is made with the fiber axis when passing from the outer medium to the fiber at a particular incident angle. We know that there exists a critical angle at the core-cladding interface in which after it crosses the angle, total internal reflection takes place in the core and when that happens, there exists a specific light ray path in which the angle of incidence at the point of entrance of light corresponds to maximum such that the total internal reflection takes place in the fiber core.

So, theoretically, all the possible light ray paths in which they can enter the optical fiber such that total internal reflection can take place forms a light cone as locus which is called acceptance cone and the angle of the cone which is made at the tip is known as the aperture angle. The numerical Aperture is considered the product of the refractive index of the outer medium and sine of half of the solid angle made from the acceptance cone. Generally, we consider air as the surrounding medium and hence we consider its refractive index as 1. So we can conclude that the numerical aperture of the optical fiber can be equal to the sine of the incident acceptance angle. We consider the angle also as the divergence of the beam.

Now when we consider the Acceptance cone, the light beam locus entering the optical fiber can be shown in the picture below.

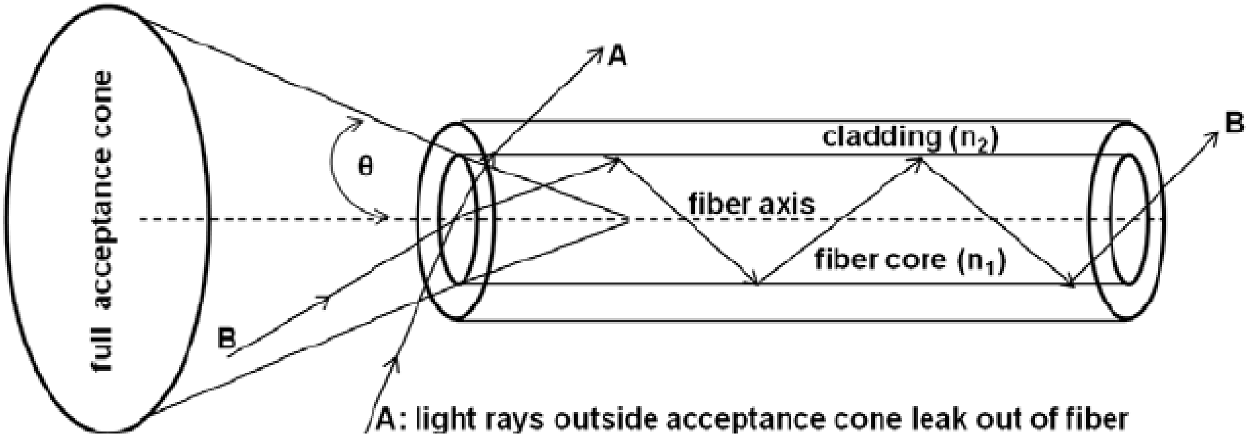


Fig. 2

In the given apparatus, as we are using Laser, we know that the laser beams spread out as they propagate, and as we consider far away from the beam, we roughly get the spread as linear approximately. This forms a cone of light which is similar to the acceptance cone. This position in which the laser beam forms a cone is called "Far-field" and we use this approach to calculate the numerical aperture and the acceptance angle of the acceptance cone. Numerical Aperture and Acceptance angle are dependent on the ratio of the refractive indices of the outside medium and the fiber medium.

We define the acceptance angle as

$$\theta a = \tan^{-1} (D/Z)$$

where

D= diameter of far-field intensity at 5% intensity

Z= distance between the detector and the fiber output end

We define the numerical aperture (NA) as

$$NA= n_a \sin (\theta_a)$$

For air, $n_a=1$, hence

$$NA = \sin(\theta_a)$$

In this experiment, we calculate the value of maximum output current, and then we take the pinhole slightly away by changing the value of Z (end-to-end displacement) by 2mm each time. By each constant value of Z, we try to calculate the maximum current output and find the value of D (transverse displacement) which is perpendicular to the fiber axis for which we observe 5% of the maximum value of the current which is observed at a particular Z. We repeat this process for a certain number of times such that the result can be accurate enough.

To understand the working procedure, refer to the following diagram.

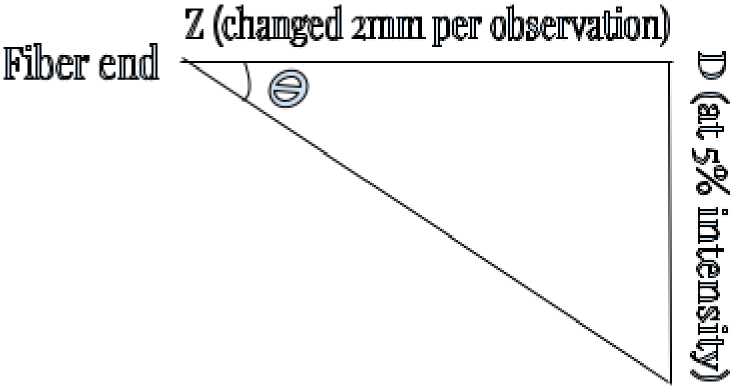


Fig. 3

Procedure:

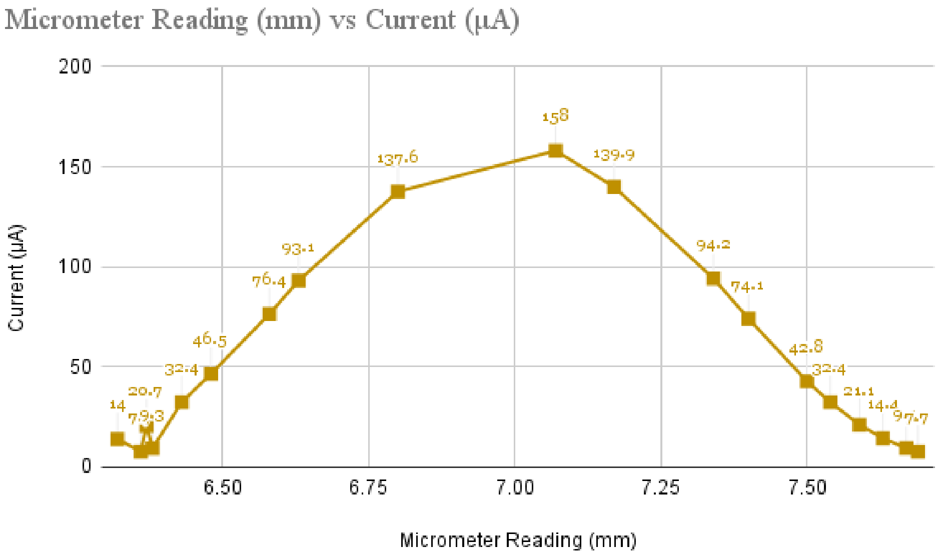
- Mount the diode laser to the laser mount.
- Mount fiber on the Laser-fiber coupler.
- Collimate the laser beam to the fiber.
- Fine adjustments can be made by tilting the fiber positioner.
- Fix the output end of the fiber to the fiber chuck holder.
- Place the pin-hole detector nearer to the tip of the fiber output.
- Take the necessary measurements.
- The experiment can be repeated for various values of ‘D’ by changing the distance ‘Z’ by 2mm each time.

Observation:

MSR: Main Scale Reading of the Micrometer
CSR: Curved Scale Reading of the Micrometer
Least Count of the Micrometer = 0.01mm

For the measurement of D, from the values of Z and output current I (mA)

S. No	Micrometer Reading		Total	Output Current (micro A)
	MSR	CSR		
1.	6	32	6.32	14
2.	6	36	6.36	7.7
3.	6	37	6.37	20.7
4.	6	38	6.38	9.3
5.	6	43	6.43	32.4
6.	6	48	6.48	46.5
7.	6.5	8	6.58	76.4
8.	6.5	13	6.63	93.1
9.	6.5	30	6.80	137.6
10.	7	7	7.07	158
11.	7	17	7.17	139.9
12.	7	34	7.34	94.2
13.	7	40	7.40	74.1
14.	7.5	0	7.50	42.8
15.	7.5	4	7.54	32.4
16.	7.5	9	7.59	21.1
17.	7.5	13	7.63	14.4
18.	7.5	17	7.67	9.4
19.	7.5	19	7.69	7.7



For the measurement of Numerical Aperture (NA), we can find maximum output current at the position using the pinhole detector reading such that the fiber is perfectly aligned and the fiber almost touches the pinhole detector such that the Z displacement is zero. After that, use the Translation stage of the pinhole detector to change Z (end-to-end displacement) each by 2mm for every observation. Record the maximum value of current and change the value of D such that 5% of the value measured at that particular Z can be seen. Record the values of Z and D respectively and hence use it to calculate the values of respective measurements of Numerical aperture by determining the sine of the angle shown in Fig.3, and we can calculate the value of Numerical Aperture by taking the mean of the values measured.

$Z_{initial}$= 11+ 22(0.01) = 11+0.22 = 11.22 mm
$D_{initial}$= 5.5 + 15(0.01) = 5.5+0.15 = 5.65 mm
$I_{initial}$= 0.7mA

For Z displacement = 2mm

1. Z_1 = 13.22 mm, D_1= 6.04mm
   Then, Z (displacement) = 2mm, D (displacement) = 6.04-5.65 = 0.39mm

$$tan\,\theta = \frac{D}{Z}$$

$$tan\,\theta = \frac{0.39}{2}$$

$$tan\,\theta = 0.195$$

$$\theta = tan^{-1}(0.195) = 0.1925\,radians$$

   So,

$$sin\theta = sin(0.1925) = 0.195$$

2. Z_2=15.22mm, D_2=6.18 mm
   Then, Z(displacement) = 4, D (displacement) = 6.18-5.65 = 0.53 mm

$$tan\theta = \frac{D}{Z}$$

$$tan\theta = \frac{0.53}{4}$$

$$\theta = tan^{-1}(0.1325) = 0.1317\,radians$$
$$sin\,\theta = sin(0.1317) = 0.1317$$

3. Z_3= 17.22 mm, D_3=6.45 mm
   Then, Z(displacement) = 6, D(displacement) = 6.45-5.65 = 0.8

$$tan\theta = \frac{D}{Z}$$

$$\theta = tan^{-1}(0.134) = 0.1332\,radians$$

$$sin\theta = \sin(0.1332) = 0.1328$$

   So, the mean of the values is the numerical aperture of the fiber

$$NA = \frac{0.195+0.1317+0.1328}{3} = 0.1531$$

Discussion:

When we increase the value of Z by 2 mm each, we can see that the value of D also decreases which gives us a relationship between D and Z such that the angle of the acceptance cone is preserved. As the fiber slowly moves away from the pinhole, we calculate the value of D, such that the intensity of the output is decreased and reaches the value which is 5% of the original maximum intensity. This gives us the value of D corresponding to the value of Z. By using both values, we calculate the value of tan(θa). After that, we can use the angle to calculate the sine of the angle with the product of the refractive index of the surrounding medium. As it is air, we consider its refractive index as 1, and the numerical aperture value can be considered as just the sine of half of the aperture angle (acceptance angle).

Result: The numerical aperture of the given optical fiber is

NA= 0.1531

Precautions:

- Make sure that the displacements in z are precisely made by a certain amount.
- Make sure that the initial readings of the translation stage are recorded correctly.
- Do not look into the laser with your eyes.

Determination of Splice Loss between Two Optical Fibers

Aim: To determine the splice loss between two given Optical Fibers.

Equipments and Components:

- Diode laser with power supply
- Graduated Optical Rail
- Laser Fiber Coupler
- Fiber chuck Holder
- Detector output measurement unit with translation stage
- Fiber Spool

Theory:

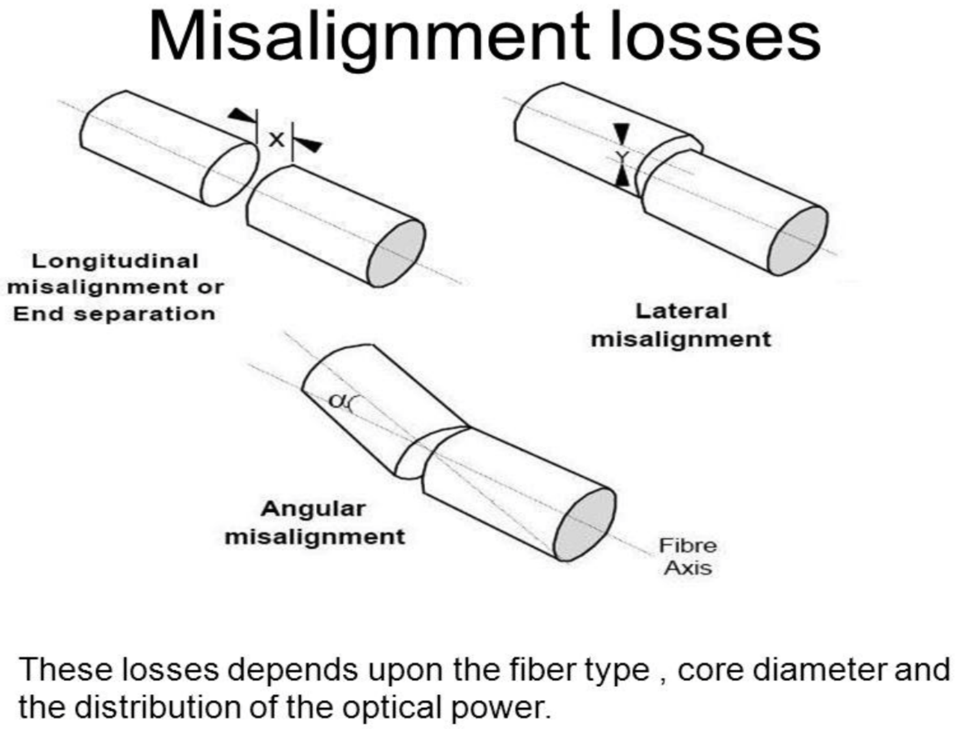
The predominant method for connecting optical fibers involves something called a Butt-Joint Connection. In any fiber joint, the ends of the optical fiber must be perpendicular to the axis of the fiber. When the mechanical alignment of the joints is not done properly, this leads to transmission loss and hence can be called “Splice Loss”.
Splice Loss can be caused by various factors. Loss can be minimized when the two fiber cores are identical and perfectly aligned. When the alignment is made, the light that is coupled into the receiving fiber’s core will be transmitted, and the remaining light becomes splice loss.

Splice loss could originate from these three primary misalignments. They are as follows.

1. Transverse Offset / Lateral Offset
2. Angular Tilt between the ends of the fiber
3. Longitudinal Offset and the end-separation

Splice loss can be caused by either of these offsets individually or can be a compound offset of any of the following combinations of the offset.

The various kinds of offsets which are mentioned can be seen in the figure below.



These losses depends upon the fiber type , core diameter and the distribution of the optical power.

Fig. 3

We will check the splice loss in the optical fiber alignment by measuring the power transmitted from one fiber to the other.

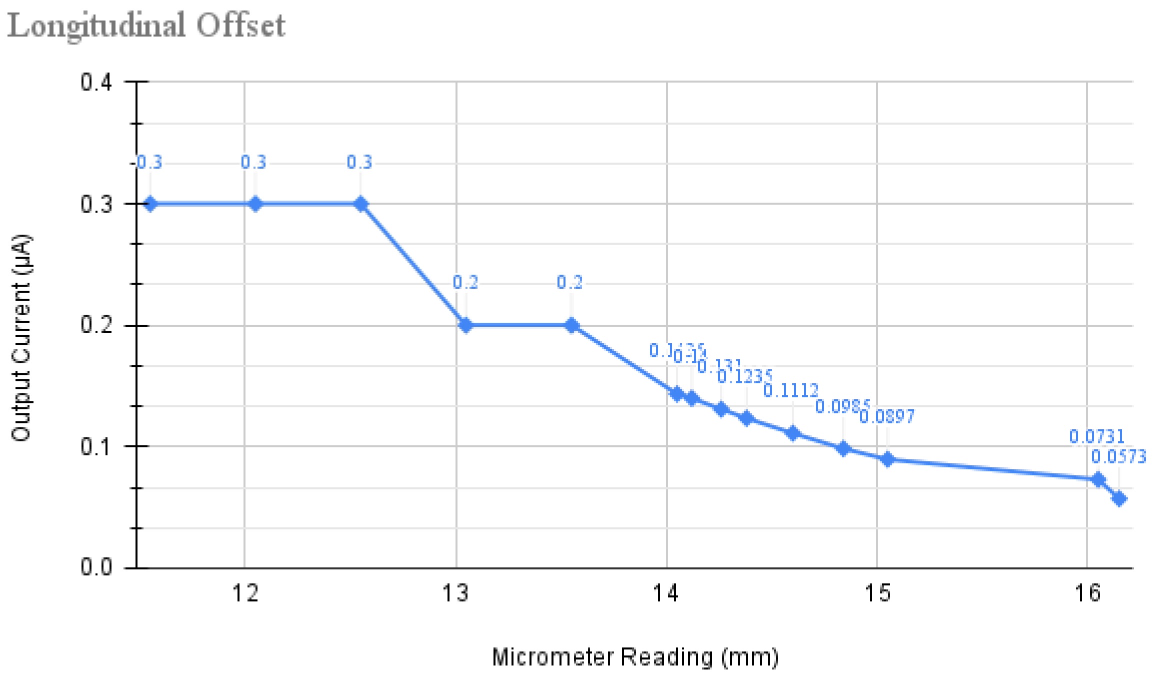
Procedure:

- Mount the diode laser to the laser mount.
- Mount fiber on the Laser-fiber coupler.
- Collimate the laser beam to the fiber.
- Fine adjustments can be made by tilting the fiber positioner.
- Fix the output end of the fiber to the fiber chuck holder.
- Place the pin-hole detector nearer to the tip of the fiber output.
- Take the necessary measurements.
- The experiment can be repeated for different misalignments and check the splice loss in each misalignment.
- Take at least ten values for observation.

Splice Loss:

Point to remember: Least count = 0.01mm
MSR = Main Scale Reading, CSR = Circular Scale Reading of the Micrometer.
Longitudinal Offset:

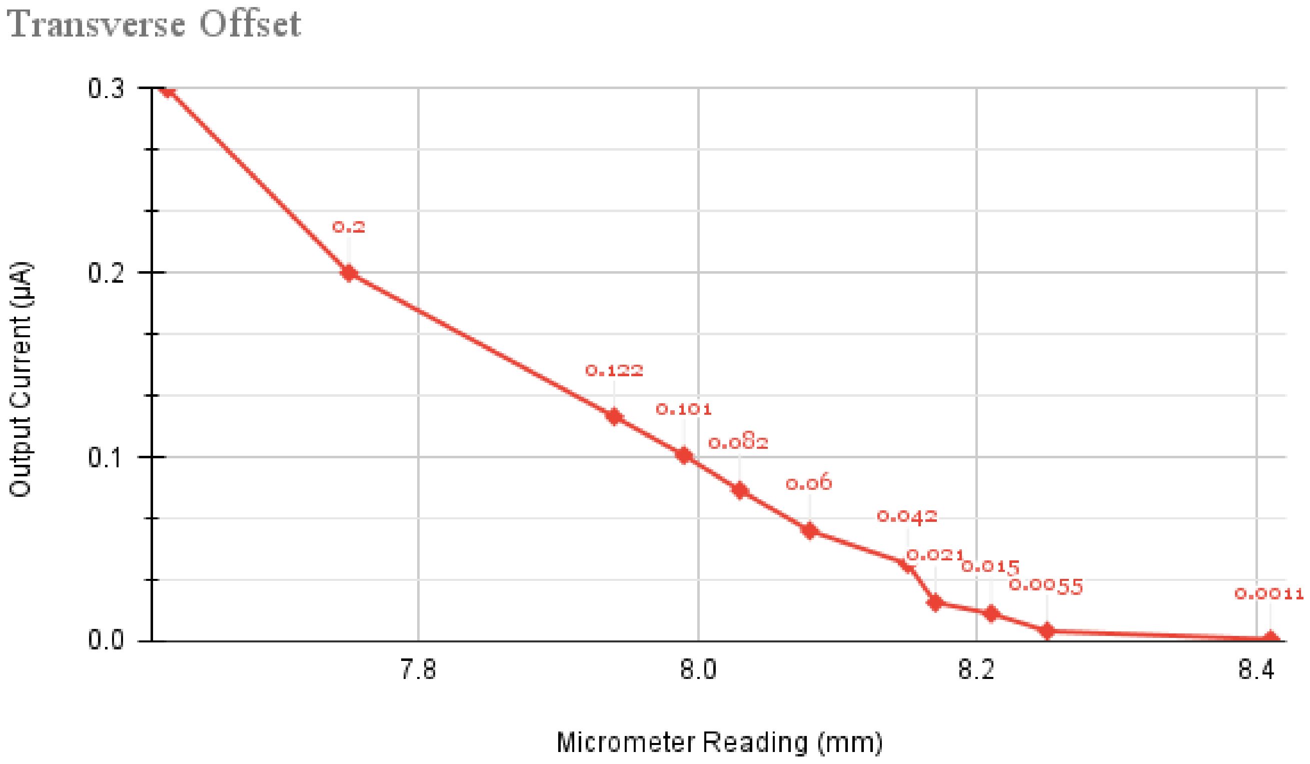
S. No	Micrometer Reading		Micrometer Reading	Output Current (µA)
	MSR	CSR	Total (mm)	
1.	11.5	5	11.55	0.3
2.	12	5	12.05	0.3
3.	12.5	5	12.55	0.3
4.	13	5	13.05	0.2
5.	13.5	5	13.55	0.2
6.	14	5	14.05	0.1435
7.	14	12	14.12	0.14
8.	14	26	14.26	0.131
9.	14	38	14.38	0.1235
10.	14.5	10	14.6	0.1112
11.	14.5	34	14.84	0.0985
12.	15	5	15.05	0.0897
13.	16	5	16.05	0.0731
14.	16	15	16.15	0.0573



Transverse Offset:

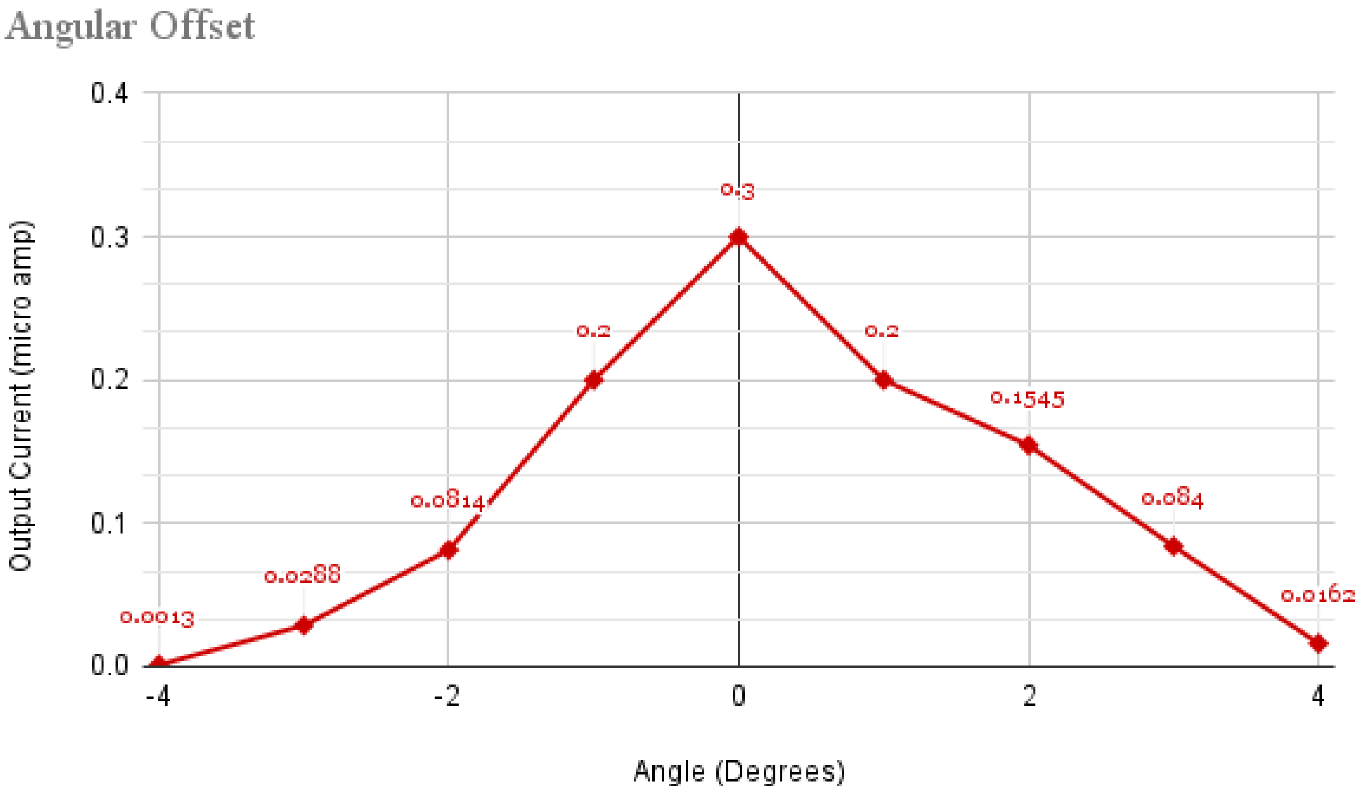
S. No	Micrometer Reading		Micrometer Reading	Output Current (micro amp)
	MSR	CSR	Total (mm)	
1.	7.5	12	7.62	0.3
2.	7.5	25	7.75	0.2
3.	7.5	44	7.94	0.122
4.	7.5	49	7.99	0.101
5.	8	03	8.03	0.082
6.	8	08	8.08	0.060
7.	8	15	8.15	0.042
8.	8	17	8.17	0.021
9.	8	21	8.21	0.015
10.	8	25	8.25	0.0055

S. No	Micrometer Reading		Micrometer Reading	Output Current (micro amp)
	MSR	CSR	Total (mm)	
1.	7.5	12	7.62	0.3
2.	7.5	25	7.75	0.2
3.	7.5	44	7.94	0.122
4.	7.5	49	7.99	0.101
5.	8	03	8.03	0.082
11.	8	41	8.41	0.0011



Tilt Offset / Angular Offset:

S. No	Angle (Degrees)	Output Current (micro amp)
1.	-4	0.0013
2.	-3	0.0288
3.	-2	0.0814
4.	-1	0.2
5.	0	0.3
6.	1	0.2
7.	2	0.1545
8.	3	0.084
9.	4	0.0162



Discussion:

As we compare all the misalignments from Transverse, Longitudinal and Angular ways, we can see that the splice loss can be observed as significantly higher in the case of Transverse offset.

Conclusion:

The splice loss between two fibers is the most sensitive to transverse misalignments.

Precautions:

- Make sure that both fibers are perfectly aligned initially to attain maximum output and minimize errors.
- Make sure that when one misalignment is being done, the other parameters are set to their initial readings again to reduce errors.
- Do not look into the laser with your eyes.

Determination of Attenuation by Fiber Cut-Back Method

Aim: To determine the attenuation in an optical fiber using the fiber cut-back method.

Equipments and Components:

- Diode Laser with power supply
- Graduated Optical Rail
- Laser Fiber Coupler
- Fiber Chuck Holder
- Detector Output measurement unit - with translation stage
- Fiber spool, etc.

Theory:

Attenuation is considered the logarithmic relationship between the optical output power and the optical input power in a fiber optical system. It can be used as a measure of the decay of signal strength or loss of the light power that occurs as the light propagates through the length of the fiber.
The method which is used to measure the attenuation in the optical fiber is called the "Cut-back method". First, we have to calculate the maximum output of the power using a detector, and then we have to cut the fiber and measure the power transmitted by the shorter length. Instead of cutting, we can take two individual measurements from each of the fibers which are made of the same material and which are long and short respectively (if cutting is not possible).

If P_i and P_f represent the input and output powers respectively, then

Loss of power can be determined in dB by the factor

$$L = 10 \log_{10} (P_i/P_f)$$

This factor can be called the attenuation L, and we can get the transmission ratio given as P_f/P_i.

Procedure:

- Mount the diode laser to the laser mount.
- Mount fiber on the Laser-fiber coupler.
- Collimate the laser beam to the fiber.
- Fine adjustments can be made by tilting the fiber positioner.
- Fix the output end of the fiber to the fiber chuck holder.
- Place the pin-hole detector nearer to the tip of the fiber output.
- Note the maximum intensity of the fiber output.
- Cut the fiber near the laser fiber coupler and note the change in outputs.

Observations:

The observations were made in the bending loss experiment.

For the optical fibers with two different lengths,

Maximum Current Output (longer fiber): 18.6 μA
Maximum Current Output (shorter fiber): 20 μA

Calculations:

In two optical fibers of different lengths. As the optical fibers are made up of the same material, we can determine the attenuation factor using the difference between two lengths of the optical fiber (provided one is known), and we can determine the attenuation without cutting the fiber.

For longer fiber (F_1), the output current was measured such that no curvature was seen between both ends of the fiber.

The maximum power output = 18.6 μA

For shorter fiber, the output current was measured such that no curvature is seen between both ends of the fiber.

The maximum power output = 0.02 mA = 20 μA

We have P_1 = 18.6 μA and P_2 = 20 μA.

Now, determine the factor

$$P_1/P_2$$

Which is equal to $\frac{18.6}{20} = 0.93$

Now, $\log_{10}(P_1/P_2)$ is $\log_{10}(0.93) = -0.03151$, and $10 \log_{10}(P_1/P_2) = -0.3151$

So, the attenuation is given as

$$L = \; -0.3151\, dB$$

Discussion:

The more the length of the optical fiber, the more the chances of energy loss. Because as the light is transmitted through the fiber, many factors including bending loss, absorption, refraction from the core and many more phenomena can contribute to the significant loss of transmission in the fiber. As the length of the fiber decreases, we can see that the factors like the ones mentioned above can be reduced and we can have a better transmission than that of a fiber of larger length.
From the bending loss experiment, as the radius of curvature decreases, the sharper the curve and hence the more the loss in power, and hence affects the output power. We can use the ratio of the reduced power with the previous maximum output power to determine the transmission loss. Now, by taking the logarithm of the ratio and multiplying it by 10, as per the formula, it gives us the power loss that happened in the optical fiber.

In the cut-back method, we can use longer fiber and shorter fiber to measure the properties and the power loss significantly without cutting the fiber.

Result:

This experiment successfully demonstrated the power loss in optical fiber in the case of bending loss and in determining the attenuation of optical fiber using optical fibers of different lengths (of the same material) without cutting the fiber.

The attenuation of optical fiber is

$$L = -0.3151 \text{ dB}$$

Precautions:

- Do not look into the laser directly.
- Make sure that the alignment is proper.

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